Chapter 5
Conservation

Businesses are finding that by conserving natural resources and energy they can cut costs, improve the environment, and improve their competitiveness. And due to the substantial amount of rinse water consumed and wastewater generated by traditional electroless copper processes, water conservation is an issue of particular concern to printed wiring board (PWB) manufacturers and to the communities in which they are located. This chapter of the Cleaner Technologies Substitutes Assessment (CTSA) evaluates the comparative resource consumption and energy use of the making holes conductive (MHC) technologies. Section 5.1 presents a comparative analysis of the resource consumption rates of MHC technologies, including the relative amounts of rinse water consumed by the technologies and a discussion of factors affecting process and wastewater treatment chemicals consumption. Section 5.2 presents a comparative analysis of the energy impacts of MHC technologies, including the relative amount of energy consumed by each MHC process, the environmental impacts of this energy consumption, and factors affecting energy consumption during other life-cycle stages, such as chemical manufacturing or MHC waste disposal.

5.1 RESOURCE CONSERVATION

Resource conservation is an increasingly important goal for all industry sectors, particularly as global industrialization increases demand for limited resources. A PWB manufacturer can conserve resources through his or her selection of an MHC process and the manner in which it is operated. By reducing the consumption of resources, a manufacturer will not only minimize process costs and increase process efficiency, but will also conserve resources throughout the entire life-cycle chain. Resources typically consumed by the operation of the MHC process include water used for rinsing panels, process chemicals used on the process line, energy used to heat process baths and power equipment, and wastewater treatment chemicals. The focus of this section is to perform a comparative analysis of the resource consumption rates of the baseline and alternative MHC technologies. Section 5.1.1 discusses the types and quantities of natural resources (other than energy) consumed during MHC operation. Section 5.1.2 presents conclusions of this analysis.

5.1.1 Natural Resource Consumption

To determine the effects that alternatives have on the rate of natural resource consumption during the operation of the MHC process, specific data were gathered through the Performance Demonstration Project, information from chemical suppliers, and dissemination of the IPC Workplace Practices Questionnaire to industry. Natural resource data gathered through these means include the following:

- Process specifications (i.e., type of process, facility size, process throughput, etc.).
- Physical process parameters and equipment description (i.e., automation level, bath size, rinse water system configuration, pollution prevention equipment, etc.).

- Operating procedures and employee practices (i.e., process cycle-time, individual bath dwell times, bath maintenance practices, chemical disposal procedures, etc.).
- Resource consumption data (i.e., rinse water flow rates, frequency of bath replacement, criteria for replacement, bath formulations, frequency of chemical addition, etc.).

Using the collected data, a comparative analysis of the water consumption rates for each of the MHC alternatives was developed. For both process chemical and treatment chemical consumption, however, statistically meaningful conclusions could not be drawn from the compiled data. Differences in process chemicals and chemical product lines, bath maintenance practices, and process operating procedures, just to name a few possibilities, introduced enough uncertainty and variability to prevent the formulation of quantifiable conclusions. A qualitative analysis of these data is therefore presented and factors affecting the chemical consumption rates are identified. Table 5.1 summarizes the types of resources consumed during the MHC operation and the effects of the MHC alternatives on resource conservation. Water, process chemicals, and treatment chemicals consumption are discussed below.

Table 5.1 Effects of MHC Alternatives on Resource Consumption

Resource	Effects of MHC Alternative on Resource Consumption
Water	Water consumption can vary significantly according to MHC alternative and level of automation. Other factors such as water and sewage costs and operating practices also affect water consumption rates.
Process Chemicals	Reduction in the number of chemical baths comprising MHC substitutes typically leads to reduced chemical consumption. The quantity of process chemicals consumed is also dependent on other factors such as expected bath lives (e.g., the number of surface square feet (ssf) processed before a bath must be replaced or chemicals added), process throughput, and individual facility operating practices.
Energy	Energy consumption rates can differ substantially among the baseline and alternatives. Energy consumption is discussed in Section 5.2.
Treatment Chemicals	Water consumption rates and the associated quantities of wastewater generated as well as the elimination of chelators from the MHC process can result in differences in the type and quantity of treatment chemicals consumed.

Water Consumption

The MHC process line consists of a series of chemical baths which are typically separated by one, and sometimes several, water rinse steps. These water rinse steps account for virtually all of the water consumed during the operation of the MHC process. The water baths dissolve or displace residual chemicals from the panel surface, preventing contamination of subsequent baths, while creating a clean panel surface for future chemical activity. The number of rinse stages recommended by chemical suppliers for their MHC processes range from two to seven, but can actually be much higher depending on facility operating practices. The number of rinse stages reported by respondents to the IPC Workplace Practices Questionnaire ranged from two to fifteen separate water rinse stages.

The flow rate required by each individual rinse tank to fulfill its role in the process is dependent on several factors, including the time of panel submersion, the type and amount of chemical residue to be removed, the type of agitation used in the rinse stage, and the purity of rinse water. Because proper water rinsing is critical to the MHC process, manufacturers often use more water than is required to ensure that panels are cleaned sufficiently. Other methods, such as flow control valves and sensors, are available to ensure that sufficient water is available to rinse PWB panels, while minimizing the amount of water consumed by the process.

PWB manufacturers often use multiple rinse water stages between chemical process steps to facilitate better rinsing. The first rinse stage removes the majority of residual chemicals and contaminants, while subsequent rinse stages remove any remaining chemicals. Counter-current or cascade rinse systems minimize water use by feeding the water effluent from the cleanest rinse tank, usually at the end of the cascade, into the next cleanest rinse stage, and so on, until the effluent from the most contaminated, initial rinse stage is sent for treatment or recycle. Other water reuse or recycle techniques include ion exchange, reverse osmosis, as well as reusing rinse water in other plant processes. A detailed description of methods to reduce water consumption, including methods to reuse or recycle contaminated rinse water, is presented in Chapter 6 of this CTSA.

To assess the water consumption rates of the different process alternatives, data from chemical suppliers and the IPC Workplace Practices Questionnaire were used and compared for consistency. Estimated water consumption rates for each alternative were provided by chemical suppliers for each MHC process. Consumption rates were reported for three categories of manufacturing facilities based on board surface area processed in ssf per day: small (2,000 to 6,000), medium (6,000 to 15,000), and large (15,000 +). Water consumption rates for each alternative were also calculated using data collected from the IPC Workplace Practices Questionnaire. An average water flow rate per rinse stage was calculated for both non-conveyorized (1,840 gal/day per rinse stage) and conveyorized processes (1,185 gal/day per rinse stage) from the data collected. The average flow rate was then multiplied by the number of rinse stages in the standard configuration for each process (see Section 3.1, Source Release Assessment) to generate a water consumption rate per day for each MHC alternative. The number of rinse stages in a standard configuration of an alternative, the daily rinse water flow rate calculated from the IPC Workplace Practices Questionnaire, and the daily water flow rate reported by chemical suppliers for each MHC alternative are presented in Table 5.2.

To determine the overall amount of rinse water consumed by each alternative, the rinse water flow rate in Table 5.2 was multiplied by the amount of time needed for each alternative to manufacture 350,000 ssf of board (the average MHC throughput of respondents to the IPC Workplace Practices Questionnaire). The operating time required to produce the panels was simulated using a computer model developed for each MHC alternative. For the purposes of this evaluation it was assumed that the water flow to the rinse stages was turned off during periods of MHC process shutdown (e.g., bath replacements). The results of the simulation along with a discussion of the data and parameters used to define each alternative are presented in Section 4.2, Cost Analysis. The days of MHC operation required to manufacture 350,000 ssf from the simulation, the total amount of rinse water consumed for each MHC alternative, and the water consumption per ssf of board produced are presented in Table 5.3. The amount of rinse water consumed for each alternative is also displayed in Figure 5.1.

Table 5.2 Rinse Water Flow Rates for MHC Process Alternatives

MHC Process Alternative	No. of Rinse Stages[a]	MHC Rinse Water Flow Rate (gal/day)	
		IPC Workplace Practices Questionnaire[b]	Supplier Data Sheet[c]
Electroless Copper, non-conveyorized (BASELINE)	7	12,880	5,700 - 12,500
Electroless Copper, conveyorized	7	8,300	3,840
Carbon, conveyorized	4	4,740	ND
Conductive Polymer, conveyorized	4	4,740	ND
Graphite, conveyorized	2	2,370	1,400 - 3,800
Non-Formaldehyde Electroless Copper, non-conveyorized	5	9,200	ND
Organic-Palladium, non-conveyorized	5	9,200	ND
Organic-Palladium, conveyorized	5	5,930	ND
Tin-Palladium, non-conveyorized	4	7,360	4,300 - 9,400
Tin-Palladium, conveyorized	4	4,740	2,900 - 7,200

[a] Data reflects the number of rinse stages required for the standard configuration of each MHC alternative as reported in Section 3.1, Source Release Assessment. Multiple rinse tanks in succession were considered to be cascaded and thus were counted as a single rinse stage with respect to water usage.

[b] Rinse water flow rate was calculated by averaging water flow data per stage from both questionnaire and performance demonstrations data (non-conveyorized = 1,840 gal/day per rinse stage; conveyorized = 1,185 gal/day per rinse stage) and then multiplying by the number of rinse stages in each process.

[c] Data ranges reflect estimates provided by chemical suppliers for facilities with process throughputs ranging from 2,000 to 15,000 ssf per day.

ND: No Data.

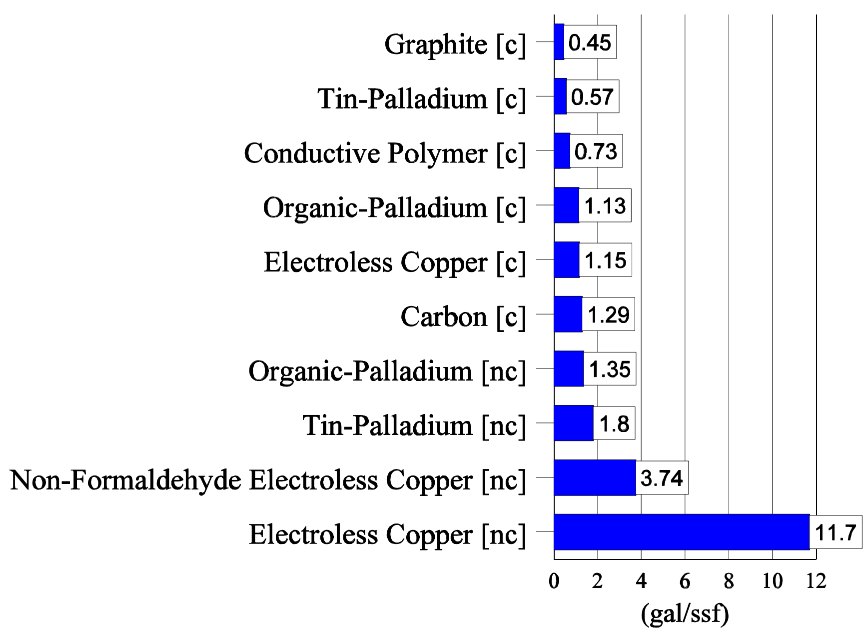
An analysis of the data shows that the type of MHC process, as well as the level of automation, have a profound effect on the amount of water that a facility will consume during normal operation of the MHC line. All of the MHC alternatives have been demonstrated to consume less water during operation than the traditional non-conveyorized electroless copper process. The reduction in water usage is primarily attributable to the decreased number of rinse stages required by many of the alternative processes and the decreased operating time required to process a set number of boards. The table also demonstrates that the conveyorized version of a process typically consumes less water during operation than the non-conveyorized version of the same process, a result attributed to the decreased number of rinse steps required and the greater efficiency of conveyorized processes. Some companies have gone a step farther by developing equipment systems that monitor water quality and usage in order to optimize water rinse performance, a pollution prevention technique recommended to reduce water consumption and, thus, wastewater generation. The actual water usage experienced by manufacturers employing such a system may be less than that calculated in Table 5.3.

Table 5.3 Total Rinse Water Consumed by MHC Process Alternatives by Board Production Rate

MHC Process Alternative	Process Operating Time[a] (days)	Rinse Water Consumed (gal/350,000 ssf)	Water Consumption Rate (gal/ssf)
Electroless Copper, non-conveyorized (BASELINE)	317.5	4.09×10^6	11.7
Electroless Copper, conveyorized	48.4	4.02×10^5	1.15
Carbon, conveyorized	95.6	4.53×10^5	1.29
Conductive Polymer, conveyorized	53.9	2.55×10^5	0.73
Graphite, conveyorized	66.1	1.57×10^5	0.45
Non-Formaldehyde Electroless Copper, conveyorized	142.8	1.31×10^6	3.74
Organic-Palladium, non-conveyorized	51.5	4.74×10^5	1.35
Organic-Palladium, conveyorized	67.0	3.97×10^5	1.13
Tin-Palladium, non-conveyorized	85.5	6.29×10^5	1.80
Tin-Palladium, conveyorized	41.8	1.98×10^5	0.57

[a] Operating time is reported in the number of days required to produce 350,000 ssf of board with a day equal to 6.8 hours of process operating time. Rinse water was assumed to be turned off during periods of process shutdown, thus the simulated operating time for each alternative was adjusted to exclude these periods of shutdown. For a more detailed description of the simulation model see Section 4.2, Cost Analysis.

Figure 5.1 Water Consumption Rates of MHC Alternatives



c: conveyorized
nc: non-conveyorized

A study of direct metallization processes conducted by the City of San Jose, California also identified reduced rinse water consumption as one of the many advantages of MHC alternatives (City of San Jose, 1996). The study, performed by the city's Environmental Services Department, included a literature search of currently available MHC alternatives, a survey of PWB manufacturing facilities in the area, and a comparative analysis of the advantages of MHC alternatives to electroless copper. The study report also presents several case studies of companies that have already implemented MHC alternatives. The study found that 14 out of 46 (30 percent) survey respondents cited reduced water usage as a prominent advantage of replacing their electroless copper MHC process with an alternative. On a separate survey question another five survey respondents indicated that high water use was a prominent disadvantage of operating an electroless copper MHC process. Although a couple of the companies studied reported little reduction in water usage, several other companies implementing MHC alternatives indicated decreases in water consumption. The study concluded that the magnitude of the reduction in water consumption is site-specific depending on the facility's former process set-up and operating practices.

Process Chemicals Consumption

Some of the resources consumed through the operation of the MHC process are the chemicals that comprise the various chemical baths or process steps. These chemicals are consumed through the normal operation of the MHC process line by either deposition onto the panels or degradation caused by chemical reaction. Process chemicals are also lost through volatilization, bath depletion, or contamination as PWBs are cycled through the MHC process. Process chemicals are incorporated onto the panels, lost through drag-out to the following process stages, or become contaminated through the build-up of impurities requiring the replacement of the chemical solution. Methods for limiting unnecessary chemical loss and thus minimizing the amount of chemicals consumed are presented in Chapter 6 in this CTSA.

Performing a comparative analysis of the process chemical consumption rates is difficult due to the variability and site-specific nature of many of the factors that contribute to process chemical consumption. Factors affecting the rate at which process chemicals are consumed through the operation of the MHC process include:

- Characteristics of the process chemicals (i.e., composition, concentration, volatility, etc.).
- Process operating parameters (i.e., number of chemical baths, process throughput, automation, etc.).
- Bath maintenance procedures (i.e., frequency of bath replacement, replacement criteria, frequency of chemical additions, etc.).

The chemical characteristics of the process chemicals do much to determine the rate at which chemicals are consumed in the MHC process. A chemical bath containing a highly volatile chemical or mixture of chemicals can experience significant chemical losses to the air. A more concentrated process bath will lose a greater amount of process chemicals in the same volume of drag-out than a less concentrated bath. These chemical characteristics not only vary among MHC alternatives, but can also vary considerably among MHC processes offered by different chemical suppliers within the same MHC alternative category.

The physical operating parameters of the MHC process is a primary factor affecting the consumption rate of process chemicals. One such parameter is the number of chemical baths that comprise the MHC process. Many of the MHC alternatives have reduced the number of chemical process baths, not counting rinse stages, through which a panel must be processed to perform the MHC function. The number of chemical baths in an MHC technology category range from eight for electroless copper to four in the graphite substitute. The process throughput, or quantity of PWBs being passed through the MHC process, also affects chemical usage since the higher the throughput, the more process chemicals are consumed. However, conveyorized processes tend to consume less chemicals per ssf than non-conveyorized versions of the same process due to the smaller bath sizes and higher efficiencies of the automated processes.

The greatest impact on process chemical consumption can result from the bath maintenance procedures of the facility operating the process. The frequency with which baths are replaced and the bath replacement criteria used are key chemical consumption factors. Chemical suppliers typically recommend that chemical baths be replaced using established testing criteria such as concentration thresholds of bath constituents (e.g., 2 g/L of copper content). Other bath replacement criteria include ssf of PWB processed and elapsed time since the last bath replacement. The practice of making regular adjustments to the bath chemistry through additions of process chemicals consumes process chemicals, but extends the operating life of the process baths. Despite the supplier recommendations, project data showed a wide range of bath replacement practices and criteria for manufacturing facilities operating the same, as well as different, MHC technologies.

A quantitative analysis of the consumption of process chemicals could not be performed due to the variability of factors that affect the consumption of this resource. Chemical bath concentration and composition differs significantly among MHC alternatives, but can also differ considerably among chemical product lines within an MHC alternative category. Facilities operating the same MHC alternative may have vast differences in both their MHC operating parameters and bath maintenance procedures which can vary significantly from shop-to-shop and from process-to-process. Because chemical consumption can be significantly affected by so many factors not directly attributable to the type of MHC alternative (i.e., process differences within an alternative, facility operating practices, bath maintenance procedures, etc.) it is difficult to perform any quantitative analysis of chemical consumption among alternatives. Further analysis of these issues is beyond the scope of this project and is left to future research efforts.

Wastewater Treatment Chemicals Consumption

The desire to eliminate chelating agents from the MHC process has been a factor in the movement away from electroless copper processes and toward the development of substitute MHC processes. Chelators are chemical compounds that inhibit precipitation by forming chemical complexes with metals, allowing the metals to remain soluble in solution well past their normal solubility limits. The elimination of chelating compounds from MHC wastewater greatly simplifies the chemical precipitation process required to effectively treat the streams. A detailed description of the treatment process for both chelated and non-chelated wastes, as well as a discussion of the effect of MHC alternatives on wastewater treatment, is presented in Section 6.2, Recycle, Recovery, and Control Technologies Assessment.

The extent to which the consumption of treatment chemicals will be reduced, if any, is dependant on several factors, some of which include the rate at which wastewater is generated (e.g., the amount of rinse water consumed), the type of treatment chemicals used, composition of waste streams from other plant processes, percentage of treatment plant throughput attributable to the MHC process, the resulting reduction in MHC waste volume realized, and the extent to which the former MHC process was optimized for waste reduction. Because many of the above factors are site-specific and not dependent on the type of MHC process a quantitative evaluation would not be meaningful. However, the San Jose study mentioned previously addressed this issue qualitatively.

The San Jose study found that 21 out of 46 (46 percent) survey respondents cited ease of waste treatment as a prominent advantage of MHC alternatives. In response to a separate question, 8 out of 46 (17 percent) respondents cited copper-contaminated wastewater as a prominent disadvantage of electroless copper. Most of the facilities profiled in the study reported mixed results with regard to the effects of MHC alternatives on wastewater treatment chemical usage. Although several companies reported a decrease in the amount of treatment chemicals consumed, others reported no effect or a slight increase in consumption. It was concluded that the benefits of the reduction or elimination of chelators and their impact on the consumption of treatment chemicals is site-specific (City of San Jose, 1996).

5.1.2 Conclusions

A comparative analysis of the water consumption rates was performed for the MHC process alternatives. The daily water flow rate was developed for the baseline and each alternative using survey data provided by industry. A computer simulation was used to determine the operating time required to produce 350,000 ssf of PWB for each technology and a water consumption rate was determined. Calculated water consumption rates ranged from a low of 0.45 gal/ssf for the graphite process to a high of 11.7 gal/ssf for the non-conveyorized electroless copper process. The results indicate all of the alternatives consume significantly less water than the traditional non-conveyorized electroless copper process. Conveyorized processes were found to consume less water than non-conveyorized versions of the same process.

A quantitative analysis of both process chemicals and treatment chemicals consumption could not be performed due to the variability of factors that affect the consumption of these resources. The role the MHC process has in the consumption of these resources was presented and the factors affecting the consumption rates were identified.